GADGET - a Gaseous Detector with Germanium Tagging

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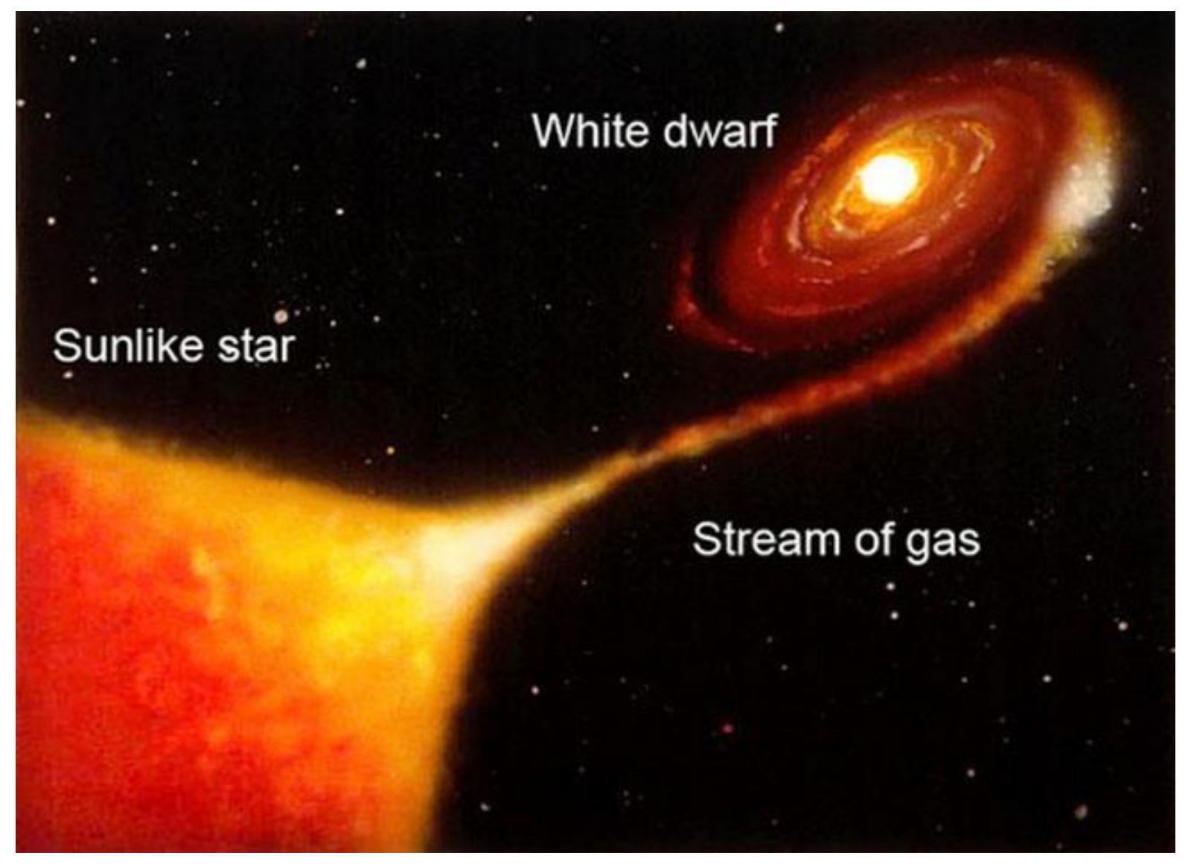
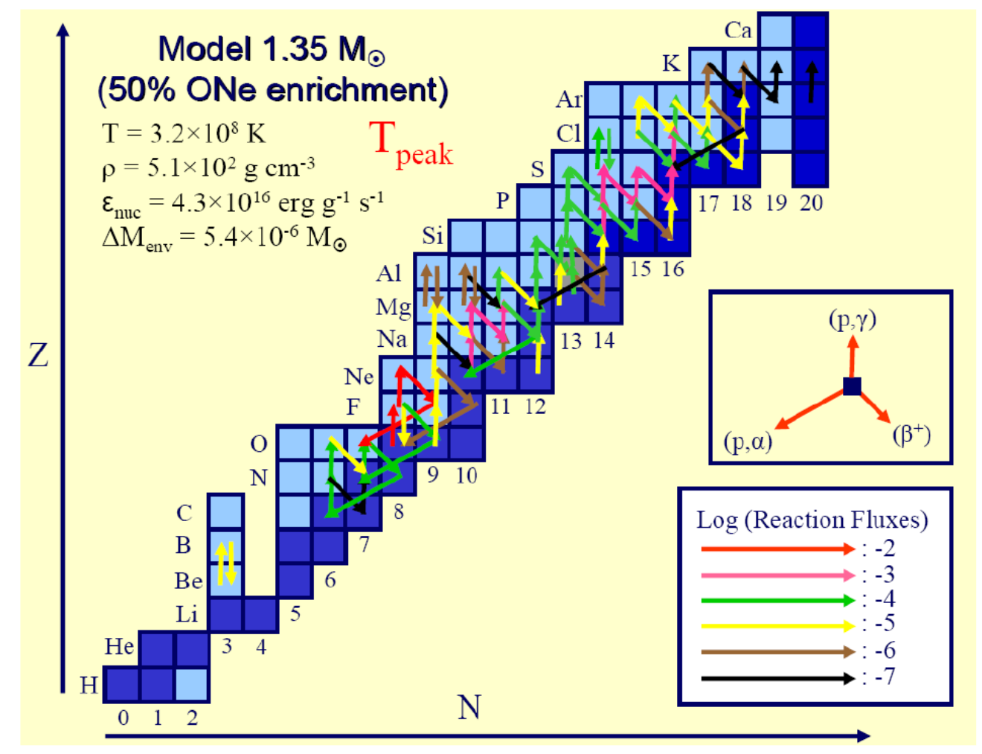
Motivation



Artist's impression of classical nova.

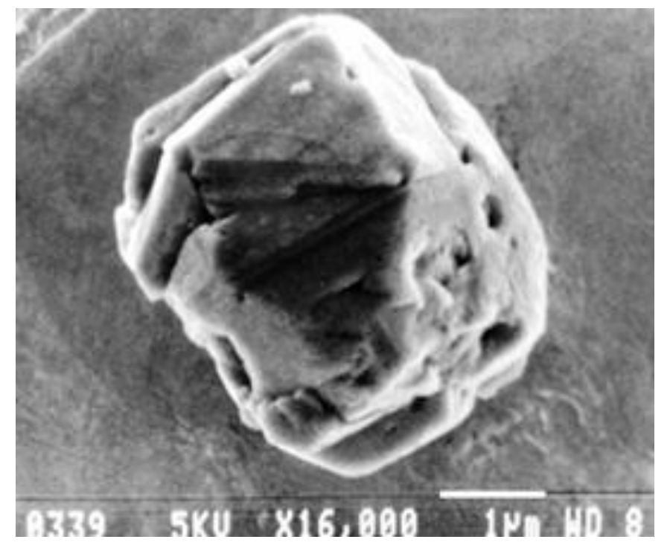
Novae and type I x-ray bursts occur in close binary star systems containing an ordinary star and white dwarf (novae) or a neutron star (type I x-ray bursts). Gravity attracts some H-rich material from the ordinary star that accumulates on the surface of the compact star. After sufficient time, the temperature and pressure at the base of the accumulating material becomes large enough for a thermonuclear runaway to occur [1].

Novae



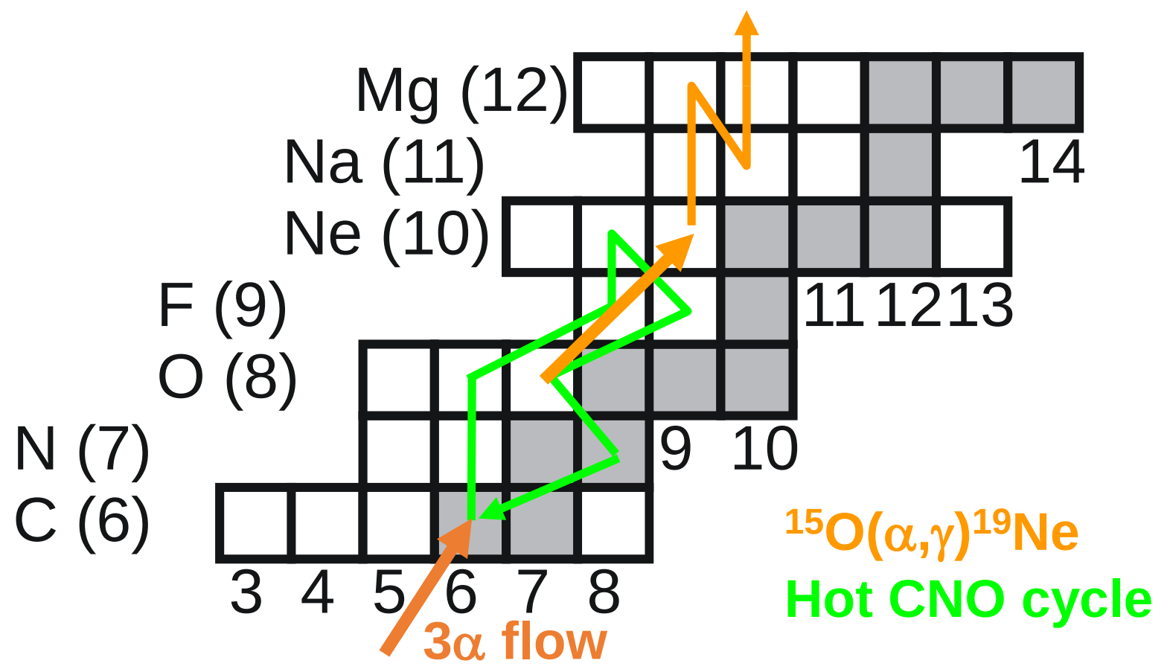
Main nuclear flow in terms of reaction fluxes at peak temperature, for a nova explosion [1].

Nucleosynthesis in novae proceeds mainly via resonant radiative proton captures and β decays. $^{30}P(p,\gamma)^{31}S$ is a potential bottleneck for nucleosynthesis in novae ($T_{1/2}$ =2.5 min)

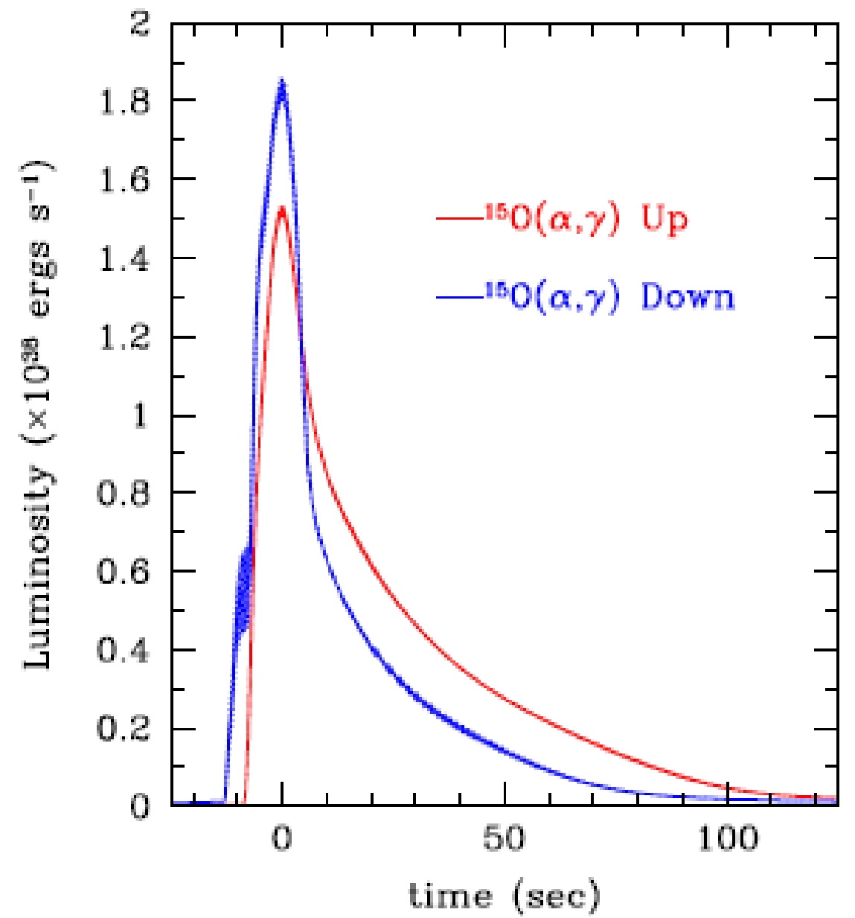


Novae are possible origin of pre-solar grains (unusual $^{30}Si/^{28}Si$ ratios)

X-ray bursts

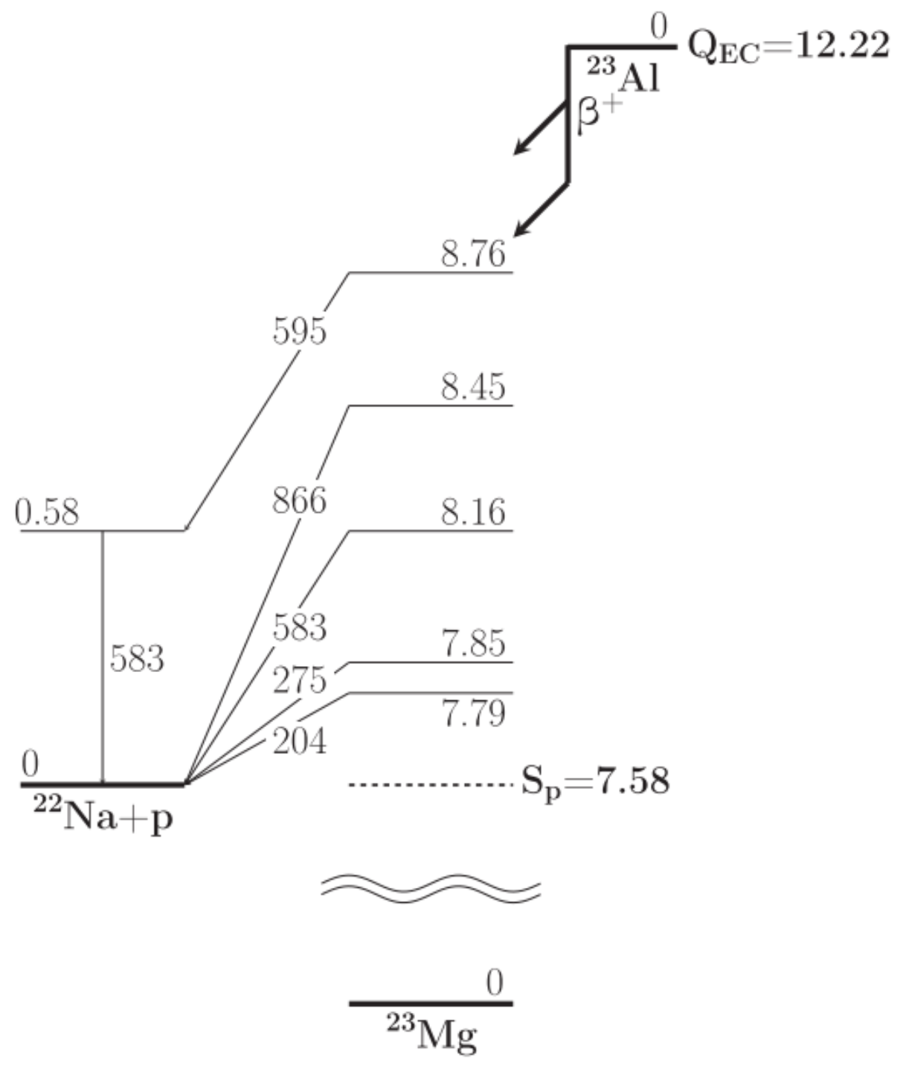


$^{15}O(\alpha,\gamma)^{19}Ne$ is one of the two routes to break-out the Hot CNO cycle and trigger the rp-process, which produces elements up to A=100.



Variation of the light emission curve of type I x-ray burst a using the upper and lower limit of the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate

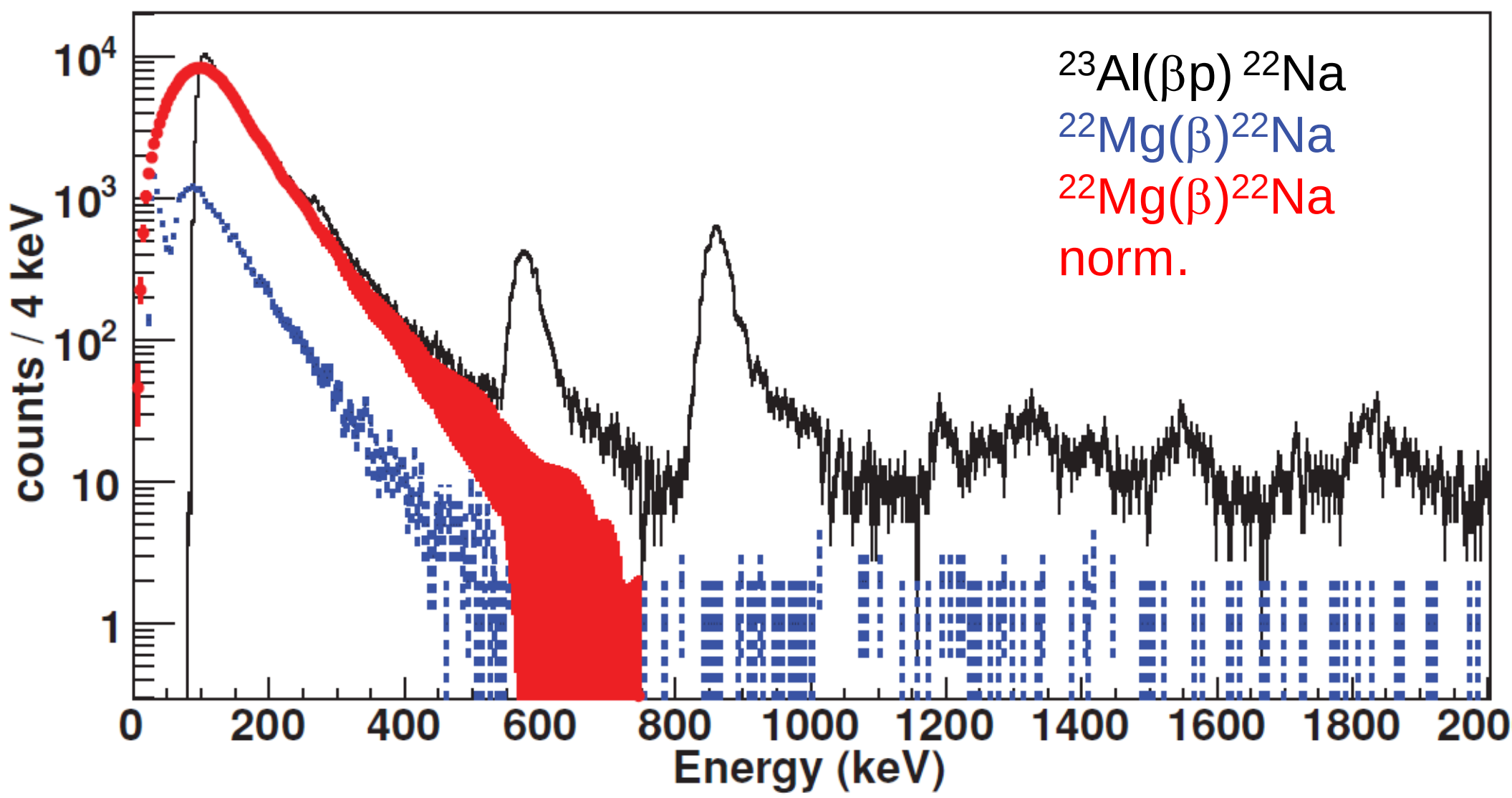
Experimental Technique



Resonant proton studied indirectly by β-delayed particle emission.

Challenges

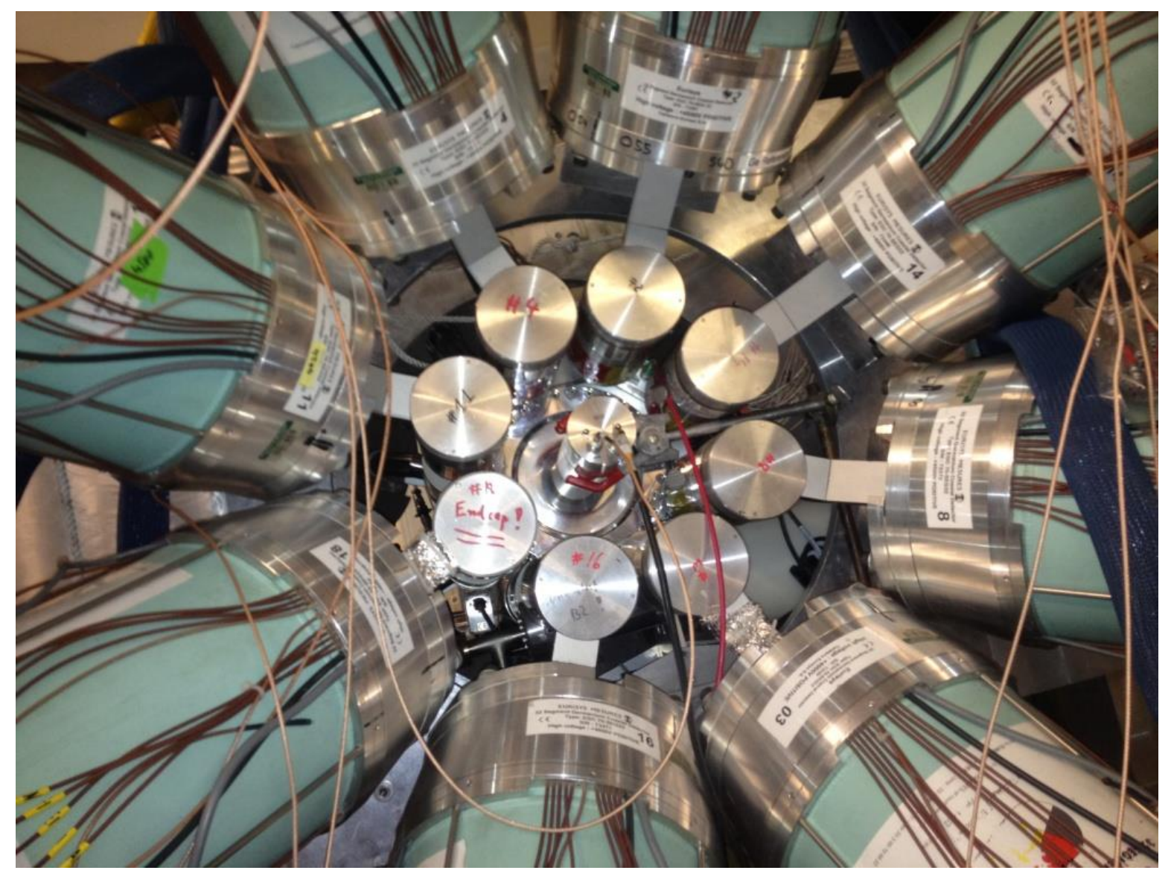
Resonance energies are close to the proton separation energy (S_p), therefore kinetic energies are very low and they overlap with the beta background in solid state detectors. In addition, proton emission competes with gamma decay, and thus sometimes has a very low probability due to Coulomb and centrifugal barriers.



β-delayed proton spectrum for ^{23}Al measured with a silicon detector. Energy deposition from β particles sums with every proton event and also produces a strong background at low energies. The spectrum is compared to ^{22}Mg β decay properly normalized [2].

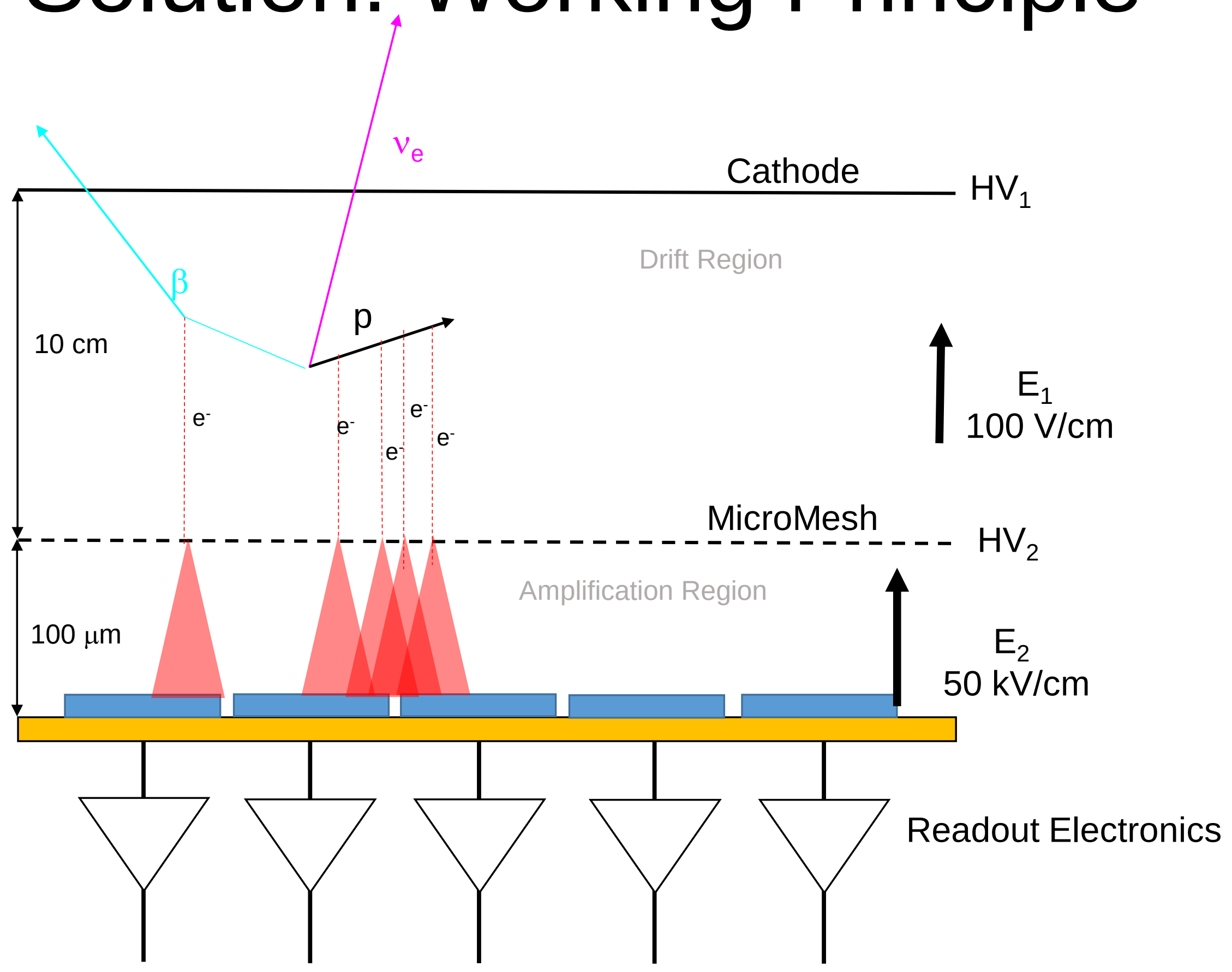
Detector requirements

- Ability to detect β-delayed protons and α-particles with kinetic energies as low as possible.
- High detection efficiency.
- Energy resolution below 8% FWHM at low energies.
- Ability to distinguish β-p and β-p-γ.
- No beta-background above 200 keV.



The detector has to fit inside the SeGA germanium array, which is ~18 cm diameter

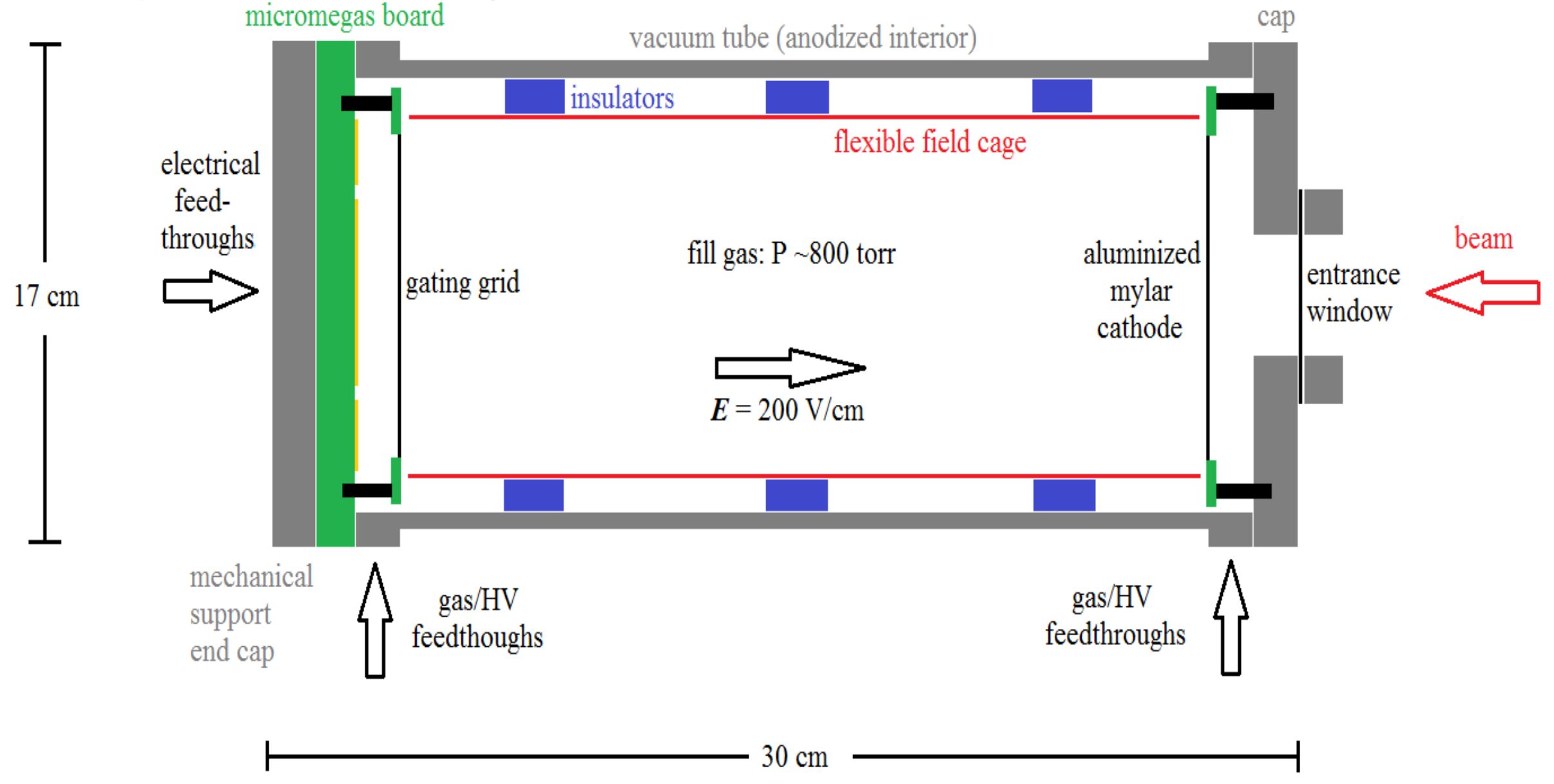
Solution: Working Principle



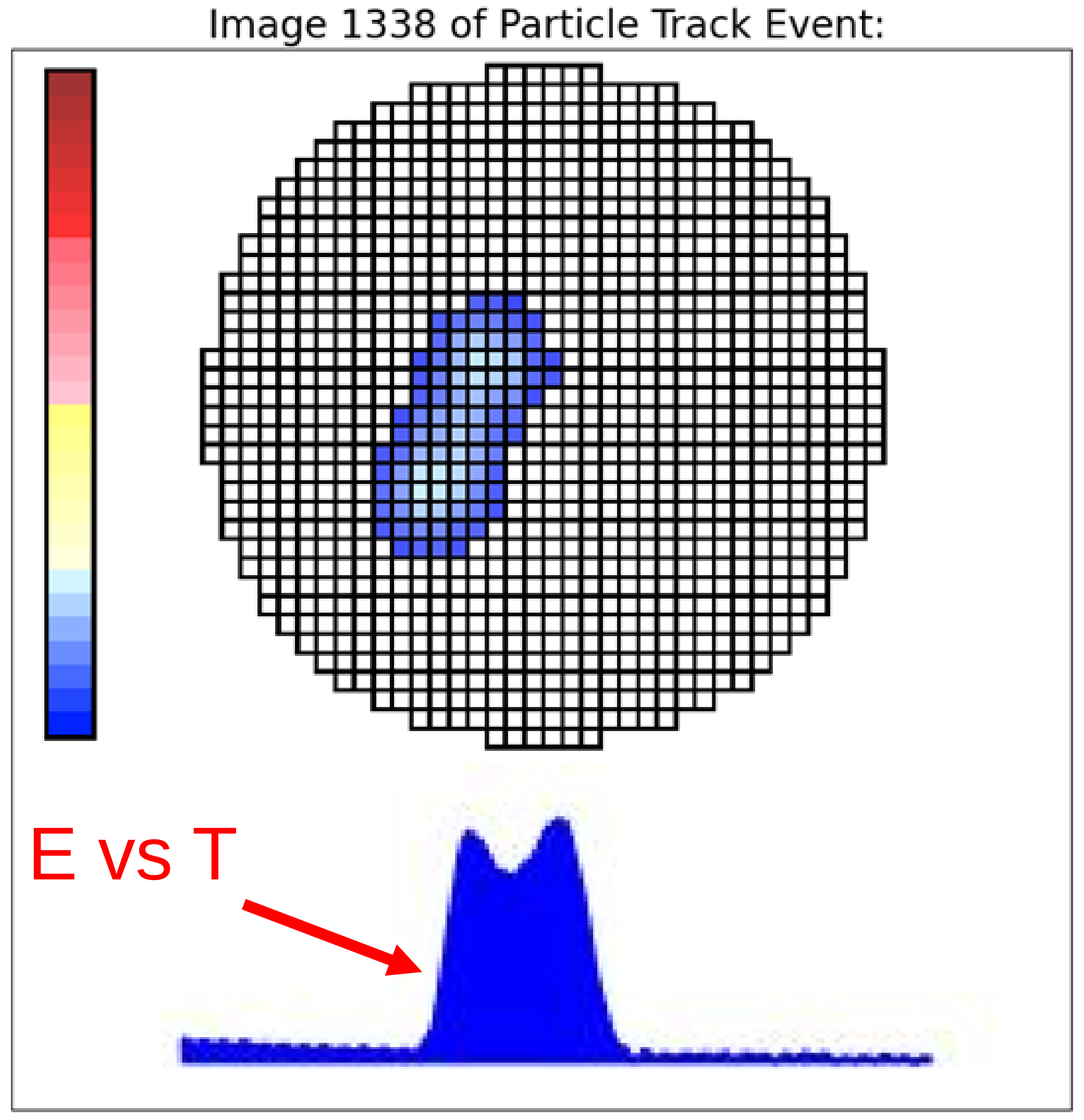
The detector uses MICROMEGAS as the amplification system [3]. Electrons produced by ionization in the gas drift in a uniform electric field toward the amplification region, where a very strong electric field produces an avalanche multiplication.

The Proton Detector

Conceptual Design

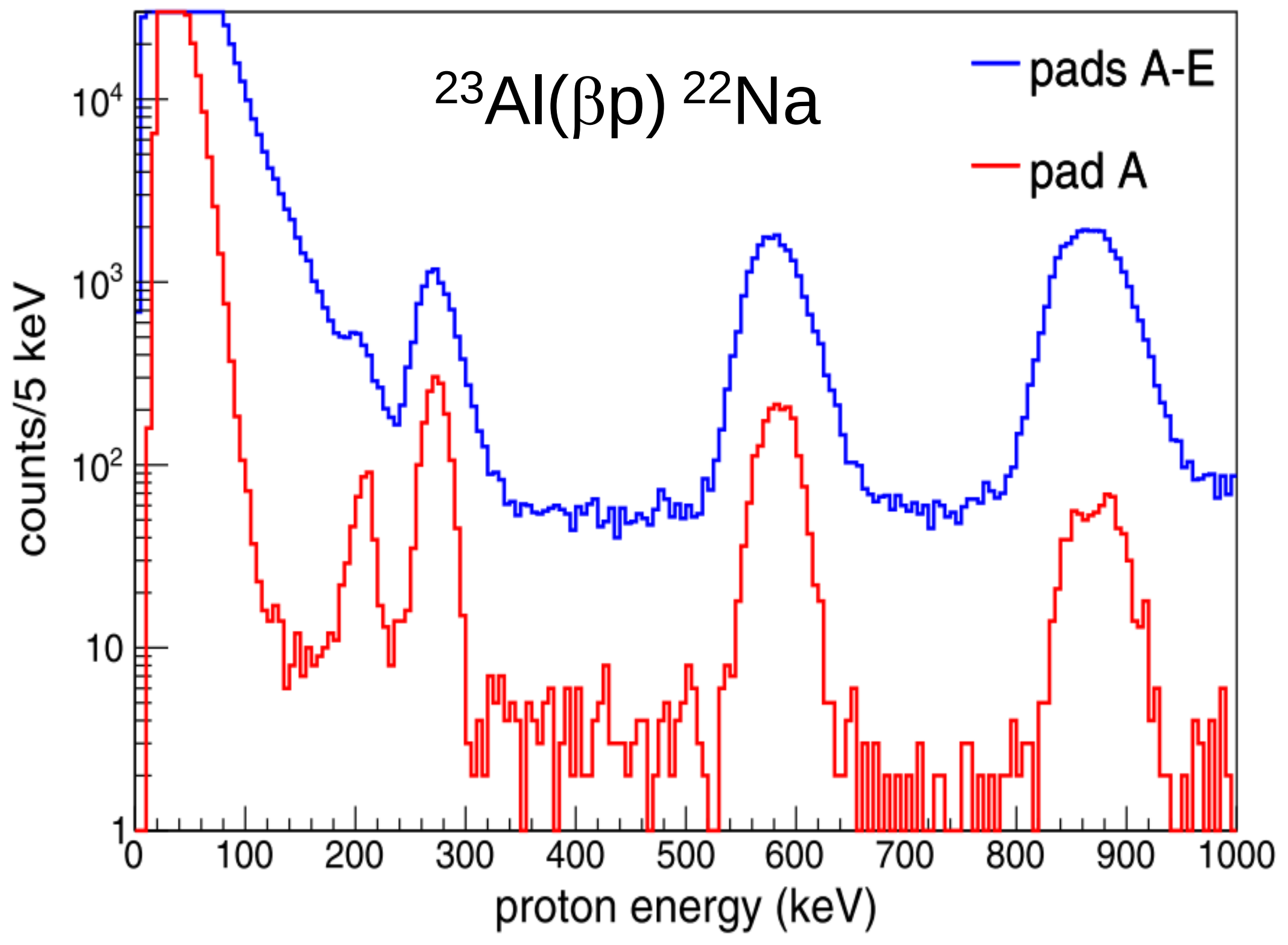


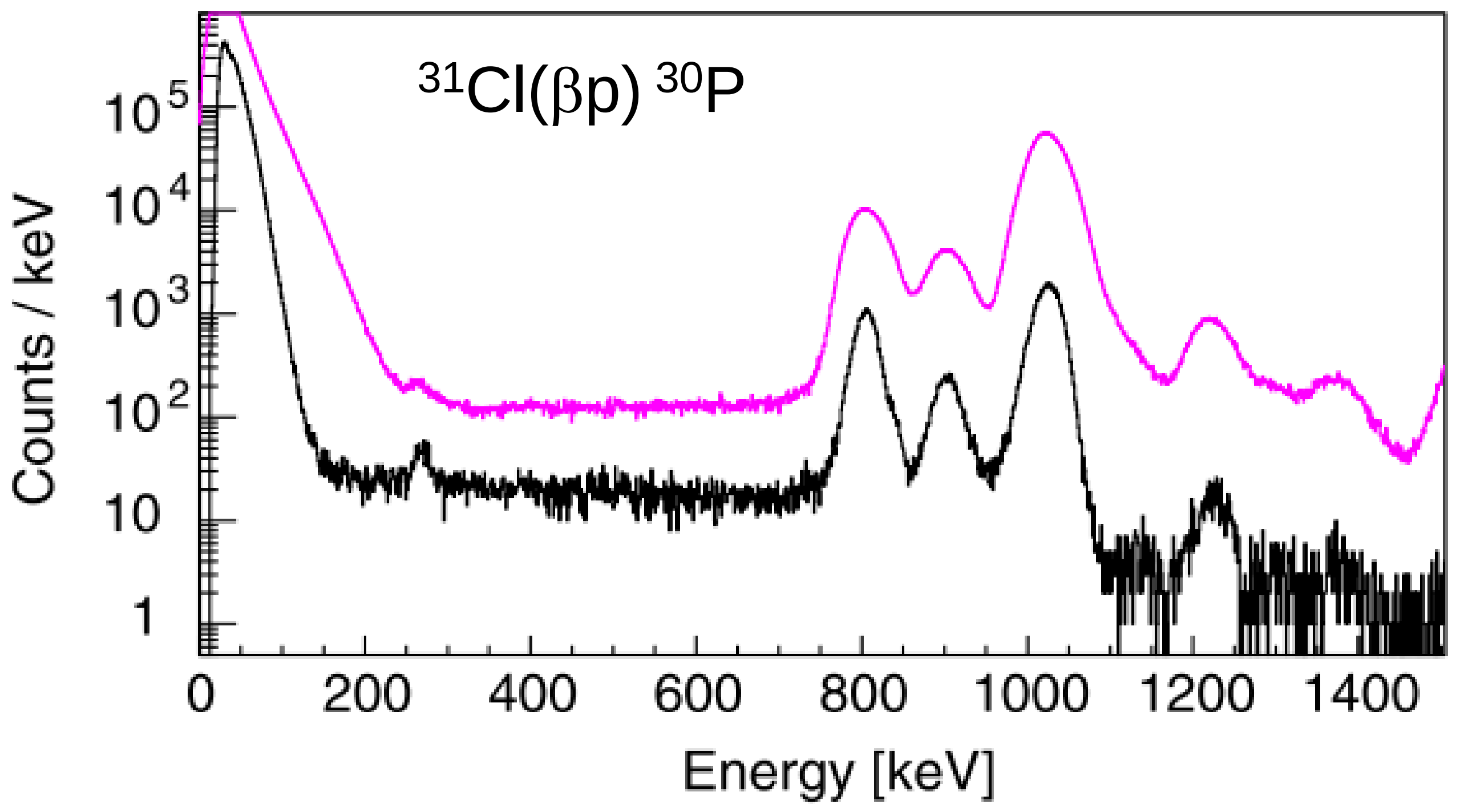
Phase II – Time Projection Chamber

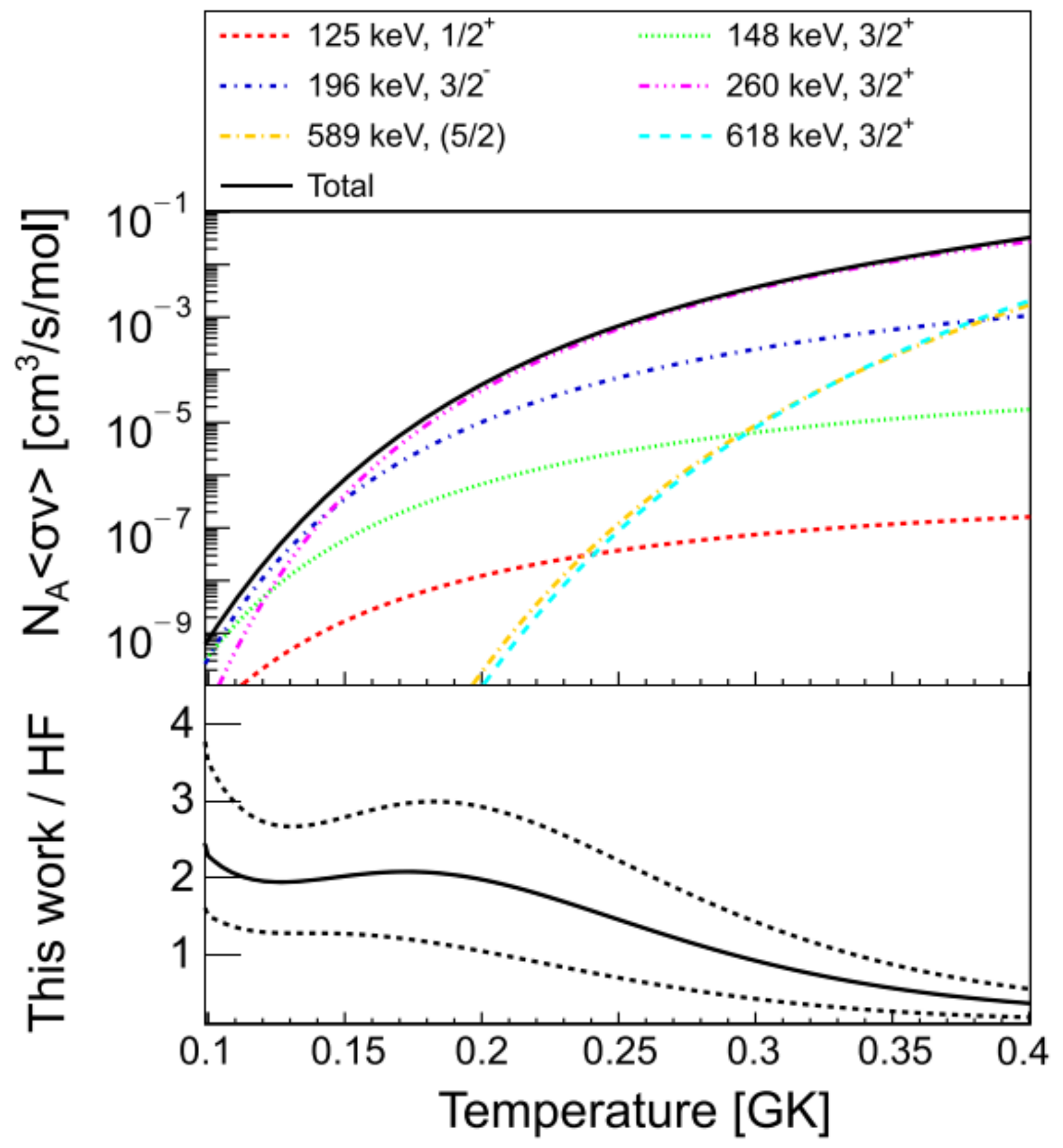


Candidate $^{21}Mg(\beta p\alpha)$ decay chain event from a calibration beam, taken at FRIB during Nov 2022 run.

Phase I - calorimetry







- $^{22}Na(p,\gamma)$ rate in nova – substantial reduction of resonance strength. (M. Friedman et al. PRC 2020).
- $^{30}P(p,\gamma)$ rate in nova – first experimental detection of the relevant resonance (T. Budner et al. PRL 2022).
- Recent (Nov 2022) run at FRIB with ^{20}Mg in TPC mode, candidate $^{21}Mg(\beta p\alpha)$ decay chain identified.

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Credit for presolar grain picture: S. Amari.
Credit for the X-ray burst light curve: R. Cyburt

REFERENCES:

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[3] Y. Giomataris *et al.* Nucl. Instr. and Meth. A, 376, 29 (1996)
[4] E. Pollacco *et al.*, Nucl. Instrum. Meth. A 723, 102 (2013)

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